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APPLICATION FOR LETTERS PATENT**

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TITLE:

“Tagging XML Query Results Over Relational DBMSs”

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of co-pending US application 09/531,802, filed 03/21/00, entitled "USING AN XML QUERY LANGUAGE TO PUBLISH RELATIONAL DATA AS XML," incorporated herein by reference.

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BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates in general to accessing databases on a network, and more specifically, to translating eXtensible Markup Language (XML) queries into queries against a relational database for the purpose of publishing relational data as XML.

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Description of Related Art

Computer systems incorporating Relational Database Management System (RDBMS) software using the Structured Query Language (SQL) interface are well known in the art. The SQL interface has evolved into a standard language for RDBMS software and has been adopted as such by both the American National Standards Organization (ANSI) and the International Standards Organization (ISO).

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In an RDBMS, all data is structured as tables. The SQL interface allows users to formulate relational operations on the tables either interactively, in batch files, or embedded in host languages such as C, COBOL, etc. Operators are provided in SQL that allow the user to manipulate the data, wherein each operator operates on either one or two tables and produces a

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new table as a result. The power of SQL lies in its ability to join and relate information from multiple tables or views, and the ability to perform complex operations with a single statement.

An alternative data format to the tables found in an RDBMS is XML, which is a tag language for describing documents. XML is a restricted form of SGML, the Standard Generalized Markup Language defined in ISO 8879. XML is more fully described at the URL:

<http://www.w3.org/TR/1998/REC-xml-19980210>

An XML document has two parts: the marked up document, and the document schema. XML documents are made up of storage units called elements, which can be nested to form a hierarchical structure. Elements can contain either parsed or unparsed data. Parsed data is made up of characters, some of which form character data, and some of which form markup. Markup encodes a description of the document's storage layout and logical structure.

XML schemas specify constraints on the structures and types of elements in an XML document. The basic schema for XML is the DTD (Document Type Definition). Other XML schema definitions are also being developed, such as XML Schema, which is described at the URL:

<http://www.w3.org/TR/1999/WD-xmlschema-1-19990924>

Several query languages have been proposed for searching and reformatting XML documents. One such language is XML-QL, which is described at the URL:

<http://www.w3.org/TR/NOTE-xml-ql>

In XML-QL, queries have the general form:

WHERE <pattern>
IN <URLs of input documents>

CONSTRUCT <output XML>

The input documents are searched for the pattern in the WHERE part of the query. Data bindings, which are specified in the pattern, are used to construct the output XML. Note that the output XML does not have to be a well-formed document with matching start and end tags, nor does it have to conform to any DTD. Important operational features of XML-QL include:

- Support for navigation in the search pattern of a query. This navigation can be expressed using path expressions.
- The ability to join and relate information from multiple input documents in a single query.
- Support for nested subqueries in the CONSTRUCT part of a query.
- The ability to generate output XML with a different structure than the input documents.

Other XML query languages that have been proposed generally support only a subset of the above operational features. For example, the XML Query Language (XQL) does not support joins, subqueries, or the ability to generate output with a different structure than its input document. XQL is described at the URL:

<http://www.w3.org/tandS/QL/QL98/pp/xql.html>

XML is likely to become a future standard for information exchange between peer data stores, and between client visualization tools and data servers. Most business data will probably continue to be stored in relational database systems, however. Thus, there is a need for a mechanism to publish and query relational data as XML.

SUMMARY OF THE INVENTION

To overcome the limitations in the prior art described above, and to overcome other limitations that will become apparent upon reading and understanding the present specification, the present invention discloses a method, apparatus, and computer program product to translate XML queries into queries against a relational database to publish relational data as XML. Each relational table is mapped to a virtual XML document, and XML queries are issued over these virtual documents. An XML query is parsed and transformed into a language-neutral intermediate representation, which is a sequence of operations describing how the output document is derived from the underlying relational tables. The intermediate representation is then translated into an SQL query over the underlying relational tables and into instructions for a tagger. The SQL query is executed, and the SQL query results are then fed into the tagger, which follows its instructions to generate the marked up output.

In order to generate the marked up output, the tagger utilizes tagger instructions which are a tagger graph generated from, and which is bound to the rewritten intermediate representation of the XML query. Each of the nodes of the tagger graph are operators which perform processing on the results of the SQL query to add tags to generate the structured XML result. The tagger walks the tagger graph applying the operators of each node to the inputs at that node to produce the structured XML document as a query result, guided by the structure of the tagger graph.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

Figure 1 is a schematic diagram of the hardware environment of the preferred embodiment of the present invention.

Figure 2 is a block diagram depicting the Xperanto system of the preferred embodiment of the present invention.

Figure 3 depicts the mapping of a relational table to its Default View in XML according to the preferred embodiment of the present invention.

Figure 4 is an exemplary XML query over the Default View and its output.

Figure 5 illustrates the Intermediate Representation of the Default View according to the preferred embodiment of the present invention.

Figure 6 illustrates the Intermediate Representation of a query over the Default View according to the preferred embodiment of the present invention.

Figure 7 illustrates the rewritten form of the Intermediate Representation according to the preferred embodiment of the present invention.

Figure 8 illustrates the translation of the Intermediate Representation to a query over the relational database according to the preferred embodiment of the present invention.

Figures 9a and 9b illustrate the Employee table and corresponding XML default view, respectively.

Figures 10a and 10b illustrate the Department table and corresponding XML default view, respectively.

Figure 11a illustrates an exemplary XML-QL query over the default views.

Figure 11b illustrates an exemplary output for the exemplary XML-QL query over the default views.

Figure 11c illustrates the tagger graph for the exemplary XML-QL query over the default views.

Figure 12a illustrates a SQL query generated to implement the outer union method of structuring SQL result data.

Figures 12b-12e illustrate the intermediate results of the SQL query of Figure 12a.

Figure 12f illustrates the results of the SQL query of Figure 12a.

Figure 13a illustrates a set of SQL queries generated to implement the node strip method of structuring SQL result data.

Figures 13b and 13c illustrate the results of the set of SQL queries of Figure 13a.

Figure 14 is a flowchart that illustrates the method steps performed by the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

OVERVIEW

The preferred embodiment of the present invention describes a distributed computing architecture for use on the World Wide Web (WWW). Specifically, a server uses a relational database system as its data store. A mapping is established from each table in the database to a virtual XML document. Clients (or other servers) query these virtual documents using XML-QL. An XML-QL query is transformed into a language-neutral intermediate representation. The intermediate representation is then translated into an SQL query over the underlying relational table, and into tagging instructions. The SQL query is executed and the SQL query results are then fed into the tagger, which follows the tagging instructions to generate the marked up output from the SQL query results. The tagging instructions take the form of a tagger graph, where each node of the graph are operators which perform processing on the results of the SQL query. Each operator requests results from its inputs and evaluates a parse tree associated with the operator to tag the results and generate the output XML. The tagger runtime applies the operators of each node to the inputs at that node to produce the structured XML document as a query result, guided by the structure of the tagger graph. Those skilled in the art will recognize that another XML query language could be used in place of XML-QL without departing from the scope of the present invention.

HARDWARE ENVIRONMENT

Figure 1 schematically illustrates an exemplary computer hardware environment that could be used with the present invention, and more particularly, illustrates a typical distributed computing architecture using a network **120** to connect clients **130** and servers **110**. Clients **130**, which may include Web browsers **132**, connect to servers **110**, which execute server software such as Web daemons **106**. Server-to-server connections may also be established using Web daemons **106**. A typical combination of resources may include clients **130** that are personal computers, or workstations, and servers **110** that are personal computers, workstations, minicomputers, or mainframes. These systems may be coupled to one another over network **120**, which may include other networks such as LANs, WANs, SNA networks, as well as the Internet.

The preferred embodiment of the present invention comprises a system known as Xperanto **104**, which maps each table in RDBMS **102** (describing contents of a database **100**) to a virtual XML document. Queries in XML-QL are issued over these virtual documents. Xperanto **104** translates an XML-QL query to an SQL query over the underlying relational tables. The SQL query is executed against RDBMS **102**, and the results of the SQL query are then marked up by Xperanto **104** to form the desired output XML.

In general, Xperanto **104** comprises data and instructions which, when read, interpreted, and executed by server **110**, cause server **110** to perform the steps of the present invention. Generally, the data and instructions are embodied in and readable from a device, carrier or media, such as memory, data storage devices, and remote devices coupled to server **110** via a data communications device (not shown).

However, those skilled in the art will recognize that the exemplary environment and components illustrated in Figure 1 are not intended to limit the present invention. Indeed, those skilled in the art will recognize that other alternative hardware environments may be used without departing from the scope of the present invention. Thus, the present invention may be implemented as a method, apparatus, or article of manufacture using standard programming and engineering techniques to produce software, hardware, firmware, or any combination thereof. In addition, the term “article of manufacture” as used herein is intended to encompass logic and data embodied in or accessible from any device, carrier, or media.

OPERATION OF THE INVENTION

Figure 2 is a block diagram that illustrates the components of Xperanto system 104. In the preferred embodiment, Xperanto system 104 is comprised of five major components: a schema mapper 200, a parser 210, a rewrite engine 220, a translator 230, and a tagger 240.

Schema mapper 200 establishes a default XML schema (the Default View) for the data stored in RDBMS 102. Each table is mapped to a virtual XML document over which XML queries are issued. These are virtual XML documents in the sense that they are preferably never materialized. Only the results of XML queries are materialized.

Parser 210 converts an XML query to a language-neutral intermediate representation. The intermediate representation is a sequence of operations that describe how the marked up output of the XML query is derived from the underlying relational tables. It includes operations to construct new XML elements from data bindings.

Rewrite engine **220** takes the intermediate representation generated by parser and converts it to an equivalent form that may be easily translated to an SQL query.

Translator **230** translates the rewritten intermediate representation into:

(1) an SQL query over the underlying relational tables and

(2) instructions for tagger **240**.

Tagger instructions describe how to generate the marked up output from the SQL query results. The SQL query is executed, and the SQL query results are fed into tagger **240**, which then generates marked up output according to its instructions.

Using the above components, Xperanto **104** provides the means to establish a mapping from a relational schema to an XML schema and the means to issue XML queries against that XML schema for the purpose of publishing relational data as XML. As its name implies, the Default View provides a default XML view of the relational data. In Xperanto **104**, alternative views of the data may be manually defined using XML queries, since each query effectively defines a different view of the data. XML queries may then be issued over these alternative views and the Default View. Note that views may be defined on top of views by recursive application of this procedure.

The Default View

Figure 3 provides an exemplary Default View for a department and employee database, consisting of a DEPT table **300** and an EMP table **310**. The DNO and ENO columns in tables **300** and **310** uniquely identify the department number and employee number, respectively. As

shown, the table name (either DEPT or EMP) is used as the tag for the outer-most XML element in the Default View. Each row in a table is mapped to a ROW element. Within a ROW element, each column of the table is mapped to an element with the column's name as its tag. Those skilled in the art will recognize that another schema mapping could be used in the Default View without departing from the scope of the present invention.

A Query Over the Default View

Figure 4 provides an exemplary XML-QL query over the Default View of Figure 3. The query provides the names of departments with more than 75 employees. The WHERE part of the query specifies the search criteria, namely that only departments with more than 75 employees are to be selected. It also specifies data bindings for DNO, NAME, and BUDGET. The CONSTRUCT part of the query specifies the structure of the output XML. As shown, a nested subquery appears within the CONSTRUCT. The subquery is used to nest employees with their departments. The binding for DNO is used to relate departments and employees in the subquery.

The Intermediate Representation

The intermediate representation is a sequence of parameterized operations that describe how the output of the XML-QL query is derived from the underlying relational tables. The input of each operation is one or more tables, and the output is another table. Each row of a table has a number of columns, where a column is either an atomic data value, such as an integer, or XML.

Various operations in the intermediate representation are described below. Each operation's name is given along with a list of input parameters. The list of input parameters is not necessarily exhaustive. Only key parameters are described:

- BIND(X, B): This operation binds variables to data values. It produces an output table consisting of all the possible data bindings B for the input document X.
- SELECT (S): This operation selects data. It applies S to each row of its input table and produces an output table consisting of rows that satisfy S.
- CONSTRUCT(T, O): This operation constructs new XML elements. For each row of the input table, the data bindings in the XML template T are instantiated. The resulting XML element is assigned to column O of the output table.
- JOIN(R): This operation has the same semantics as a join in an RDBMS. R is a predicate that is used to relate the two input tables.
- GROUP(C, X, O): This operation groups related XML elements. The input table is grouped on column(s) C. Within a group, column X of the input table is concatenated and assigned to column O in the output. If C is empty, one group is created for the whole input table.
- NEST(R, X, O): This operation nests XML elements in a parent-child relationship. It takes two input tables, with one playing the role of the parent and the other playing the role of the child. R is a predicate that used to relate a parent and child. Children are grouped with their parent. Within a group, column X of the child table is concatenated and assigned to column O in the output.

Those skilled in the art will recognize that another intermediate representation with different operations could be used without departing from the scope of the present invention. In general, operations are needed to establish the selection criteria to be applied to the input documents, the required relationships between the input documents, and the structure of the output XML.

Figure 5 shows the intermediate representation for the Default View of DEPT table **300** in Figure 3. Working from the bottom up, DEPT table **300** is accessed and input to a CONSTRUCT operation **510**. For each row, data bindings from the DNO, NAME, and BUDGET columns are used to construct a ROW element, which is assigned to the RowEle column. ROW elements are then concatenated by a GROUP operation **520** and assigned to the Rows column. Finally, a second CONSTRUCT operation **530** adds the DEPT tag, and the resulting XML is assigned to the DefView column. The intermediate representation for the Default View of the EMP table would look similar.

Figure 6 shows the intermediate representation for the query in Figure 4. As shown, the starting point is the Default View of the DEPT and EMP tables **300** and **310**. BIND operations **600** and **610** map the Default View back into a table. The marked up output is constructed by operations **630**, **640**, and **650**. CONSTRUCT operation **630** constructs EMP elements, and NEST operation **640** groups EMP elements with the same DNO. Finally, CONSTRUCT operation **650** generates a BIGDEPT element for each department with size greater than 100, as selected by SELECT operation **620**.

The Rewrite Engine

Rewrite engine **220** takes the intermediate representation generated by parser **210** and converts it to an equivalent form that may be easily translated to an SQL query. More specifically, operations to construct and group XML elements are reordered to appear last in the rewritten intermediate representation. The steps to carry out the rewrite process are as follows:

- 1) Let S denote the sequence of CONSTRUCT, GROUP, and CONSTRUCT operations following a table access for the Default View of a table T. Whenever S is followed by a BIND operation B, eliminate both S and B, leaving just the table access for T.
- 2) Let N denote a NEST operation and S denote any sequence of CONSTRUCT and GROUP operations for the child input of N. N is replaced by a JOIN operation, followed by S and a new GROUP operation G, which performs the child grouping that was previously done by N.

Figure 7 shows the rewritten version of the intermediate representation in Figure 6. As shown, the operations to construct and group XML elements now appear last. Figure 7 is for a query with only single level of nesting. However, deeper levels of nesting can be handled by repeated application of steps 1) and 2).

Those skilled in the art will recognize that different rewrite steps could be used without departing from the scope of the present invention. In general, rewrite engine **220** converts the intermediate representation to an equivalent form where operations to generate the structure of the output XML are performed last.

Translation

Translator **230** takes the intermediate representation produced by rewrite engine **220** and translates it to: (1) an SQL query over the underlying relational tables; and (2) tagger instructions. More specifically, operations on the intermediate representation are partitioned into two groups: operations that select and relate data **730**, and operations that construct and group XML elements **740**. Operations that select and relate data **730** are translated into an SQL query, while operations that construct and group XML elements **740** (including CONSTRUCT operation **700**, GROUP operation **710**, and CONSTRUCT operation **720**) are translated into tagger instructions.

Figure 8 shows the translation of the intermediate representation into an SQL query **800** and tagger instructions **810**. A straightforward translation from the intermediate representation into SQL query **800** is shown. Those skilled in the art will recognize that a different SQL translation could be used without departing from the scope of the present invention. Any SQL query that establishes the selection criteria and relationships among data will suffice. The intermediate representation itself is used as the tagger instructions **810**. Those skilled in the art will recognize that a different instruction format could be used without departing from the scope of the present invention. Any instruction format that describes how to generate the marked up output from the results of the SQL query will suffice.

Query Execution

To produce the XML result, SQL query **800** is executed and its results are fed into tagger **240** of Xperanto **104**. Tagger **240** uses tagger instructions **810** to generate the marked up output.

Tagger Operation

In order to generate the marked up output, tagger **240** utilizes tagger instructions **810** which are a tagger graph generated from, and which is bound to the rewritten intermediate representation of the XML-QL query. Each of the nodes of the tagger graph are operators which perform processing on the results of the SQL query to add tags to generate the structured XML result.

The tagger graph is generated from the intermediate representation and, therefore, reflects the structure of the resultant XML document. The tagger runtime **240** walks the tagger graph applying the operators of each node to the inputs at that node to produce the structured XML document as a query result, guided by the structure of the tagger graph.

In addition, the SQL queries are generated from the intermediate representation such that the data from the query is ordered to additionally reflect the structure of the resultant XML document. Generating the SQL queries such that the results reflect the structure of the resultant XML document, by computing ordering inside the relational engine, allows the tagger runtime **240** to be a constant space tagger which prepares its results using a single pass over its inputs, buffering at most a single row from each input stream.

The tagger runtime **240** will be illustrated by an example. It should be noted that this example is different from the previous example above in order to more fully illustrate the various operators.

The exemplary database's schema is:

Employee = (workdept, eno, lastname)

Department = (deptno, deptname, size)

Figures 9a and 9b illustrate the Employee table and corresponding XML default view, respectively. Figures 10a and 10b illustrate the Department table and corresponding XML default view, respectively. The default view schemas are generated for both tables in the same manner as described above in conjunction with Figure 3. By providing XML default views, a user can query seamlessly over relational data using an XML query language. This allows developers who would prefer to work solely in XML to do so, without regard to the fact that the underlying data is relational data.

The exemplary XML-QL query over the default views is illustrated in Figure 11a. This exemplary query is designed to retrieve all of the departments, the employees associated with a department and to structure the result such that the employees of a department are nested within the department.

The WHERE part of the query defines variable bindings and the CONSTRUCT clause defines the structure of the result of the XML query, which is itself an XML document. In the WHERE part, the query binds variables \$DEPTNO and \$DEPTNAME to DEPTNO and DEPTNAME tag values (e.g. 1 and Spiffy Computer) for each row tag in the default XML view of the DEPARTMENT table (DefaultDepartment) and, hence, to DEPTNO and DEPTNAME column values in table DEPARTMENT. For each row in DEPARTMENT, the CONSTRUCT part of the query is run to produce a result. The root tag of each result is "dept" having an attribute called "name" which is set to the value of the variable \$DEPTNAME which is bound to the DEPTNAME column in a row in DEPARTMENT. The tag "emplist" is nested with "dept"

and its sub elements are generated using a nested XML-QL query whose output is defined by the CONSTRUCT clause of the nested query. The nested query selects employees in table EMPLOYEE, by querying the XML default view of the EMPLOYEE table whose attribute WORKDEPT matches variable \$DEPTNO defined in the outer query. That is, the nested query
 5 selects employees who work in a department. For each employee in a department, the tags "employee" and "name" along with the value of variable \$ENAME are generated and nested within tag "emplist". Closing matching tags are then produced. A sample output for this query is given by Figure 11b.

As illustrated in Figure 11b, the sample output lists four result departments: SPIFFY COMPUTER, PLANNING, INFORMATION CENTER and DEVELOPMENT CENTER. The first department has three employees, the second has a single employee, the third department has three employees and the fourth department has no employees.

The following discussion first describes the different tagger operators for building a tagger graph, followed by the tagger graph for the present example. Next, the preferred SQL query methods to appropriately structure the resultant data are discussed. Then, how the tagger runtime generates the elements for the resulting data, i.e. tags the resulting data, by calling and applying the operators when walking the tagger graph is described.

Tagger Operators

A tagger operator is either a scalar operator, an aggregate operator, or an input operator. These operators are the main runtime elements of the tagger graph and are the initial nodes reached during the walk of the graph.

- 5 ● Tagger Scalar - A tagger scalar operator tags results which correspond to constants, columns and scalar functions, excluding aggregate functions. A tagger scalar operator can have many inputs which can be any tagger operator. The scalar operator assembles results by requesting the next input on all its inputs and computing its result from these inputs. The first (leftmost) input is called the representative input. The first input is the parent of any other inputs attached to the operator. For example, if employees are aggregated under the departments to which they belong, the representative input is on department. If the representative input has no more data, the scalar operator signals, as output, that it neither has any more data.
- 10 ● Tagger Aggregate - A tagger aggregate operator has a single input and tags results which correspond to aggregate computations based upon aggregate functions. To compute its result, the operator draws individual results from its input until its input signals that it has no more data for the aggregate operator. The aggregate operator then renders and returns its result. An aggregate operator can render a result if no input exists in the input stream for its aggregate, or it can signal "no input" as its output depending upon its setting during tagger graph creation.
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Tagger Input - A tagger input operator manages the delivery of data from the RDBMS to the tagger operators. It is the interface between the tagger runtime graph and the intermediate representation. The intermediate representation is used to generate SQL queries to extract data from RDBMSs. The tagger input operator buffers and manages database query results using tagger row streams (described below) embedded within the tagger input operators. There is a tagger input operator for each level in the XML result tree.

Each of the tagger operators comprise a tagger parse tree. A tagger parse tree is an element of a tagger operator that is used to compute a result column of the operator. A tagger parse tree can be a constant, a column of a lower tagger operator serving as input to this operator, or it can be a tagger function which can have a list of arguments including constants, columns and functions. To prepare an output row of a tagger operator, inputs for the operator are retrieved and each tagger parse tree is executed to compute its result. The result of each tagger parse tree is buffered into a row which is the tagger operator's result.

The tagger row streams, which are utilized by the tagger input operator, manage database results and determine the end of a group of tuples which is needed for aggregate computations. For example, if the tagger is aggregating the set of employees under each department, the row stream needs to determine if the end of a set of employees in a department has been reached. Two alternative methods are used to establish this. One is based upon outer union queries and type indicators produced as constants in an SQL query submitted to the RDBMS. Using outer union, a single SQL query is submitted to the database; its result contains all data required by the

tagger runtime. The other alternative is based upon examining the parent keys of grouped objects to determine the end of a group. This second technique is called node strip. Using node strip, multiple queries are submitted to the database; there is one query for each level in the output tree.

5 Tagger Graph

The tagger graph for the present example is illustrated in Figure 11c. As previously described, the tagger runtime walks the tagger graph, calling the operators to perform functions on the inputs in order to generate the output XML document.

10 The top scalar operator **1100** in the present example has two inputs. The first or representative input retrieves results for departments. The second input retrieves results for employees. Generally, for each input to tagger scalar operator **1100**, starting from the left most input, the next results from the input are retrieved. The parse trees associated with the output of scalar operator **1100** are evaluated to produce its results based upon the results retrieved from the inputs. When top scalar operator **1100** makes the calls to retrieve results from its inputs, this
 15 algorithm is transitively applied to all lower operators when each lower operator, in turn, requests results from its inputs. Therefore, ultimately, tagger input operator **1102** retrieves the results of the SQL query corresponding to the department names. These are retrieved from input operator **1102** by scalar operator **1100**. Tagger input operator **1108** retrieves the results of the SQL query corresponding to the employee names and these are retrieved from input operator **1108** by scalar
 20 operator **1106** which tags each individual result with <employee> and <name> tags. Aggregate operator **1104** retrieves individual tagged employees from scalar operator **1106** to build a list of

employees associated with each department which are also retrieved by scalar operator 1100.

Scalar operator 1100 creates tags for each department and nests the list of employees associated with each department to form the output XML document.

5 SQL Query Methods for Generating Structured Results

1. Outer Union

Since outer union row streams are the result of a single query issued to the relational DBMS to retrieve all data required for the XML query result, all tagger input operators share this row stream. Each branch of the union query has been adorned with extra constant valued
 10 columns which represent the type of result retrieved by that branch of the union. Sorting the result on the type columns guarantees that sub nodes of a node in the tree appear in the result after a node and that sub nodes are grouped together. For the purposes of aggregate computation, determining that the end of a group has been reached can be established strictly using the type indicators.

15 Figures 12a-12f illustrate the use of the outer union method for appropriately ordering the resultant data. Figure 12a illustrates a SQL query generated to implement the outer union method of structuring SQL result data for the present example. This SQL query is generated from the intermediate representation of the XML-QL query of Figure 11a. The portion of the query indicated by 1 performs a natural join of the Employee and Department tables, selects the
 20 deptno and lastname columns of the new table created by the natural join, and generates a new table. The top level select produces a table which has a deptno, a null, a lastname, and an

indicator column. Note that the value in the indicator column is a constant value of 1. The null column is added in order to perform a union with the results of the query portion indicated by 2. The results of this portion of the query are illustrated in Figure 12b.

The query portion indicated by 2 selects the deptno and deptname column from the Department table and generates a new table having deptno, deptname, null, and indicator columns. Note that the value in the indicator column for this portion is a constant value of 0. The results of this portion is illustrated in Figure 12c.

The query performs the union of these two tables, illustrated in Figure 12d, and orders the result of the union, as illustrated in Figure 12e. The results of the union are first sorted according to the parent nodes. This groups all parent nodes and their child nodes together. The result is then sorted according to the indicator so that parent nodes appear before child nodes. In the present example, the results are sorted according to deptno values, which aren't retrieved from the query, and indicator column values. This groups all result rows belonging to the same department together, in the order of parent then child, i.e. department then employee.

Furthermore, by examining the value of the indicator column, the tagger runtime can determine for which tagger input operator a row is destined. The number of indicator columns is equal to the depth of the result XML tree less one. In the present example, the depth is two so there is a single indicator column. The final results from the query are illustrated in Figure 12f.

Structuring the results in this manner inside the relational engine allows for the tagger runtime to be a constant space tagger which, at most, buffers a single row from the results of the SQL query, because all nodes and their descendants are grouped together in the results with

parent nodes occurring before child nodes. In the present example, input operators **1102** and **1108** utilize a shared stream row manager to retrieve the first row of the results (Figure 12f) into the buffer.

When upper most scalar operator **1100** requests results from its inputs, it starts with the leftmost input, i.e. left tagger input operator **1102**. As left tagger input operator **1102** is called by upper most scalar operator **1100**, it computes and returns a single row to upper most scalar operator **1100**. Once it has received this input, upper most scalar operator requests results from the next input, moving from left to right, i.e. aggregate operator **1104**. Aggregate operator **1104** then requests results from its input, which causes scalar operator **1106** to request the next row from right input operator **1108**. The indicator of this row is 1. Right input operator **1108** retrieves the next row and returns it to scalar operator **1106**, which in turn returns it to aggregate operator **1104**. Because aggregate operator **1104** aggregates results, it continues to request rows in this manner until the indicator is no longer 1. When the next row no longer has an indicator of 1, right tagger input operator **1108** returns an end of stream signal, which is propagated up to aggregate operator **1104** in the same manner as a row of results. The end of stream signal causes aggregate operator **1104** to compute and return its result to upper most scalar operator **1100**. In turn, upper most scalar operator **1100** once again requests results from its left-most input and this cycle continues until the rows returned from the SQL query are exhausted.

2. Node Strip

Alternatively, tagger node strip row streams are individual result streams belonging to each node in the result tree. Using the node strip approach results in the generation of the two queries in the present example; the first retrieves results belonging to left tagger input operator **1102** and the second retrieves results belonging to right tagger input operator **1108**.

Results belonging to sub elements are sorted according to the keys of their parent elements and each references the keys of all its parent nodes in the tree in order to determine the end of a stream in aggregate computations. In the present example, results for nested employees are sorted so that they will be grouped by department number and sorted in the same order as department results (i.e., on the department number key DEPTNO). During tagger runtime, key values are used to determine the end of a group from the input stream; for example, if all employees within a department have been exhausted.

A set of SQL queries implementing this method are illustrated in Figure 13a. The query corresponding to the left tagger input operator is designated as 1 and the query corresponding to the right tagger input operator is indicated by 2. The results of the query designated by 1 is illustrated in Figure 13b and the results of the query designated by 2 are illustrated in Figure 13c. Note that the results illustrated in Figure 13c are the results corresponding to the child nodes and they are sorted by and contain a reference to the parent node, DEPTNO.

Structuring the results in this manner inside the relational engine allows for the tagger runtime to be a constant space tagger which, at most, buffers a single row from the results of each SQL query. When upper most scalar operator **1100** requests results from its inputs, it starts with

the leftmost input, i.e. left tagger input operator **1102**. As left tagger input operator **1102** is called by upper most scalar operator **1100**, it computes and returns a single row to upper most scalar operator **1100**. Once it has received this input, upper most scalar operator requests results from the next input, moving from left to right, i.e. aggregate operator **1104**. Aggregate operator **1104** then requests results from its input, which causes scalar operator **1106** to request the next row from right input operator **1108**. Right input operator **1108** retrieves the next row and returns it to scalar operator **1106**, which in turn returns it to aggregate operator **1104**. Because aggregate operator **1104** aggregates results, it continues to request rows in this manner.

For each result retrieved by right tagger input operator **1108**, it compares the DEPTNO column for each row retrieved for employee sub elements to the DEPTNO value of the row retrieved by left input operator **1102** for the department elements. When the next row's DEPTNO value no longer matches that of the row retrieved by left input operator **1102**, right tagger input operator **1108** returns an end of stream signal, which is propagated up to aggregate operator **1104** in the same manner as a row of results. The end of stream signal causes aggregate operator **1104** to compute and return its result to upper most scalar operator **1100**. In turn, upper most scalar operator **1100** once again requests results from its left-most input and this cycle continues until the rows returned from the SQL query are exhausted.

Generating Output XML

The general algorithm for tagger runtime **240** is described by the following steps starting from the top tagger scalar operator **1100**:

1. For each input to a tagger operator, starting from the left input to the right, retrieve the next result from the input.
2. Evaluate the parse trees associated with the output of the operator and produce its results based upon the results retrieved from the inputs.

While the algorithm is applied to the top scalar operator to retrieve the overall XML query result, the algorithm is transitively applied to all operators when each operator, in turn, requests results from its inputs.

The following describes how each operator, generally, implements the above algorithm:

- Tagger Scalar Operator --- If the representative tagger input operator has no more results, then signal the end of stream for this operator. Retrieve the next input row from each input stream starting from the left most input to the right most input. Evaluate the parse trees in the output of the operator producing the result.
- Tagger Aggregate Operator --- This operator has a single input. Depending upon the operator's setting, it can signal end of stream on an empty input stream, or it can render a result for the empty input stream. For each aggregate function in the operator's output, call initialize on the operator to prepare the operator for input. While there is input, evaluate the aggregate functions for each input row. When the end of stream is reach on the input (the end of a sub

group call also signals an end of stream), terminate the execution of each aggregate function thereby rendering each aggregate function's result.

- Tagger Input Operator --- As previously described, outer union and node strip are two alternative execution models for tagger input operators. The following describes how the tagger input operators implement the above algorithm for each model:

- Outer Union --- If no row is present in the buffer, retrieve the next result from the database and place it in the buffer. If no more results remain in the input stream, propagate the end of stream signal as the output of the operator. Compare the type indicators in the retrieved row to the indicators of the tagger input operator. If the indicators match, then the end of stream hasn't been reached for this input stream and compute and return the buffered row and release the buffer. If the indicators don't match, signal an end of stream and maintain the row in the buffer.

- Node Strip --- If no row is present in the buffer, retrieve the next result from the database and place it in the buffer. If no more results remain in the input stream, propagate the end of stream signal as the output of this operator. This step is identical for both outer union and node strip approaches. Compare the key values for the parent key columns in both this row and the parent row. For example, employees are sub elements of their departments, and the value of the DEPTNO column in the row retrieved for employee sub elements is compared with the row retrieved from department elements. If the value of the key columns differ, signal an end of stream as output, otherwise, compute return the buffered row as output.

The tagger operators implement a number of functions when evaluating the parse trees to generate the XML output. The following are the set of functions performed by top scalar operator **1100** when it evaluates its parse tree:

```
cr8_elem ("dept",
5   cr8_attr_list (cr8_attr ("name", LEFT_TIP.$DEPTNAME)),
   cr8_fragment_list (cr8_elem ("emplist",
                           cr8_attr_list(),
                           cr8_fragment_list (AGG.$TAGGED_EMP_AGG))))
```

The top tagger scalar operator **1100** calls function `cr8_elem` (short for `create_element`) to tag incoming results from lower operators. The element "dept" is created along with its attribute list containing a single attribute. The call to "cr8_attr" creates attribute "name" and sets its value to the variable \$DEPTNAME of the left tagger input operator **1102** over DEPARTMENT. The call to "cr8_attr_list" wraps the attribute in a list of attributes. The call to "cr8_fragment_list" builds nested subelements of "dept". A single sub element "emplist" is created. It has no attributes and its contents are derived from the result of the tagger aggregate operator **1104**.

The following are the set of functions performed by tagger aggregate operator **1104** when it evaluates its parse tree:

```
cr8_fragments (SCALAR.$TAGGED_EMP_SCALAR) as $TAGGED_EMP_AGG
```

The tagger aggregate operator **1104** calls function "cr8_fragments" (short for `create_fragments`) to build the list of employees associated with each department. Individual tagged employee results are retrieved from the lower scalar operator **1106**.

The following are the set of functions performed by lower scalar operator **1106** when it evaluates its parse tree:

```
cr8_elem ("employee", cr8_attr_list(),
          cr8_fragment_list ("name",
                             cr8_attr_list (),
                             cr8_fragment_list (RIGHT_TIP.$ENAME)))
```

as \$TAGGED_EMP_SCALAR

The lower scalar operator **1106** creates an "employee" tag using the "cr8_elem" function. The element has no attributes and has a sub element drawn from the right tagger input operator **1108** and bound to the variable \$ENAME.

Both tagger input operators **1102** and **1108** retrieve their inputs from the database indirectly through a tagger row streams manager embedded within the tagger input operator as previously described; utilizing either the outer union or node strip models.

In addition, each tagger operator implements a "next" method which produces the following result row in its stream of results from the above described functions. The "next" method returns an end-of-stream signal when all results in the stream have been exhausted or the end of a group has been reached.

Also, to request results from its input, each operator implements a "getObject (int)" method which returns the object in the ith column of a lower operator's result. The desired column is passed as parameter to the "getObject" method.

Figure 14 is a flowchart that illustrates the method steps performed by the preferred embodiment of the present invention.

Block **1400** represents the parsing of an XML query. Schema mapper **200** establishes a default XML schema (the Default View) for the data stored in RDBMS **102**. Each table is mapped to a virtual XML document over which XML queries are issued. Parser **210** converts the XML query to a language-neutral intermediate representation, which is a sequence of operations that describe how the marked up output of the XML query is derived from the underlying relational tables.

Block **1402** represents the rewriting of the intermediate representation to an equivalent form that may be easily translated into an SQL query. More specifically, operations to construct and group XML elements **740** are reordered to appear at the top in the rewritten intermediate representation.

Block **1404** represents the translation of the intermediate representation to: (1) SQL query **800** over the underlying relational table; and (2) a tagger graph for tagger **240**. Operations that select and relate data **730** are translated into SQL query **800**, which establishes the selection criteria and relationships among data. Operations that construct and group XML elements **740** are translated into a tagger graph, which describe how to generate the marked up output from the results of SQL query **800**.

Block **1406** represents the execution of SQL query **800**. The results of SQL query **800** are fed into tagger **240**, which follows the tagger graph to generate the marked up output.

Block **1408** represents the algorithm of tagger **240** to follow the tagger graph to generate and output the result XML document. For each input, the next result is retrieved from the input. The parse trees associated with the output of the operator are evaluated and produce its results are produced based upon the results retrieved from the inputs. This algorithm is applied transitively to each operator of the tagger graph when each operator, in turn, requests results from its inputs.

In the foregoing description of the preferred embodiment, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and that structural and functional changes or other modifications and variations may be made without departing from the scope of the present invention. For example, any type of computer, such as a mainframe, minicomputer, or personal computer, could be used to implement the present invention. In addition, the present invention is not limited by specific document formats or document query languages. For example, the present invention could also be used with HTML or SGML. The description of the preferred embodiment has been presented for the purposes of illustration and description, and is not intended to be exhaustive or to limit the invention to the precise form disclosed. It is intended that the scope of the invention be limited not by this detailed description but rather by the claims appended hereto.